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(54)   **Multistandard DMT DSL transmission system**

(57)   A digital subscriber line transmission system using QAM modulation on several equally spaced discrete tones, uses, at a high transmission rate, $N = $ 2048/p or 4096/p tones spaced by 4.3125p KHz, where p is a power of 2.
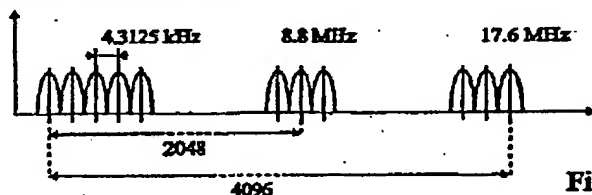
Fig 5

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Description

[0001] The present invention relates to discrete multitone (DMT) based digital subscriber line (DSL) transmission systems which allow high speed communication on twisted pair telephone lines. The invention relates more specifically to a VDSL (Very high speed DSL) system which can be used with several existing or forthcoming standards.

[0002] Figure 1 shows the spectrum of a signal transmitted according to the ADSL and ADSL-Lite (asymmetric DSL) standards. The ADSL standard uses quadrature amplitude modulation (QAM) on each of 256 tones, the tones being equally spaced by 4.3125 KHz. Thus, as shown, the last tone has a frequency of 1.104 MHz. The ADSL-Lite standard only uses the first 128 tones.

[0003] As shown, a gap is left at the beginning of the spectrum for "plain old telephone services" (POTS).

[0004] According to the ADSL standards, most of the tones are used for reception, the few remaining tones being used for transmission, hence the term "asymmetric DSL".

[0005] Current VDSL standardization proposals devise the use of frequencies up to 11.04 MHz.

[0006] Figure 2 shows the spectrum of a signal transmitted by a conventional VDSL time domain duplexing (TDD) system such as described in "VDSL Alliance SDMT VDSL Draft Standard Proposal", ETSI STC/TM6, 973T13R0, Lannion, France, September 29-October 3, 1997. This system uses 256 or 512 tones spaced, respectively, by 43 or 21.5 KHz. The last tone has a frequency of 11.04 MHz. All the tones are used for a same transmission direction at one time, the transmission direction being switched every other transmitted symbol.

[0007] Figure 3 shows the spectrum a signal transmitted by a conventional VDSL "Zipper" system as disclosed in patent application WO 97/06619. It uses 2048 tones spaced by 5.375 KHz, the last tone also having a frequency of 11.04 MHz. In this system, the tones used for transmission and for reception are chosen dynamically in order to cancel near-end crosstalk and near-end echoes.

[0008] Figure 4 very schematically shows a DSL transmission system at one end of a telephone line 10. An inverse fast Fourier transform (IFFT) circuit 12 receives N complex frequency domain coefficients, where N is the number of tones used by the system, i.e. 128 or 256 for the ADSL standards, 256 or 512 for the VDSL TDD system, and 2048 for the VDSL Zipper system. The IFFT circuit 12 generates, for each set of N coefficients, a time domain symbol. A symbol is thus the sum of N sinusoidal subcarriers of different frequencies corresponding respectively to the tones. The amplitude and phase of each subcarrier is determined by the corresponding frequency domain coefficient received by the IFFT circuit. The symbols are processed by a digital-to-analog converter 14 and a low-pass filter 16 and then transferred onto telephone line 10 through a hybrid line interface 18.

[0009] A cyclic prefix and a cyclic suffix are added to the symbol output by IFFT circuit 12 at 19. The cyclic prefixes are intended to eliminate intersymbol interference in the far-end receiver by providing a guard period during which the propagation transients of the line may decay. The cyclic suffix is intended to cancel the effects of the sampling of discontinuities in near-end echoes.

[0010] Line interface 18 also receives incoming symbols from line 10. These incoming symbols are provided to a fast Fourier transform (FFT) circuit 20 through a low-pass filter 22, an analog-to-digital converter 24 and, if necessary, through a time domain equalizer 26.

[0011] The above mentioned cyclic prefix, in order to accomplish its role, has a minimum length independent of the symbol length. In DSL systems using a relatively low number of tones, such as ADSL and VDSL TDD, the transmitted symbols are short, whereby the minimum length of the cyclic prefix is so long that it causes a substantial efficiency loss in the data transmission. In this case, the cyclic prefix is chosen shorter than necessary and it is the role of the time domain equalizer 26 to complement the short cyclic prefixes in the elimination of the intersymbol interference.

[0012] In DSL systems using a large number of tones, such as in the VDSL Zipper system, the generated symbols are so long that the cyclic prefixes can be chosen at the necessary length without substantially affecting the efficiency of the transmission. In such systems, the time domain equalizer 26 is omitted.

[0013] Moreover, in a VDSL TDD system, since the IFFT circuit and FET circuit are never used at the same time, it is a single circuit which performs both functions.

[0014] The IFFT and FFT circuits operate at least at twice the frequency of the last tone used by the system, i.e. 1.104 MHz for ADSL-Lite, 2.208 MHz for ADSL, and 22.08 MHz for the known VDSL systems.

[0015] It is clear that the ADSL standards and forthcoming VDSL standards differ in many ways (the number of used tones, the spacing between the tones, the operation frequency of the IFFT and FFT circuits...), which is likely to increase the number of types of modems capable of exploiting these standards.

[0016] An object of the invention is to provide a transmission system which will allow a single modem to exploit many DSL standards with a low complexity.

[0017] To achieve this and other objects, the invention provides a digital subscriber line transmission system using QAM modulation on several equally spaced discrete tones. At a high transmission rate, the system uses $N = 2048/p$ or $4096/p$ tones spaced by $4.3125p$ KHz, where p is a power of 2.

[0018] According to an embodiment of the invention, for transmitting at a low transmission rate according to an ADSL standard, only the first $n = 128$ or 256 tones are used with $p = 1$.

the frequency of clock CK is chosen equal to 17.664 MHz.

[0049] A VDSL-TDD transmission would be modified to use a maximum frequency of 17.664 or 35.328 MHz instead of 22 MHz.

[0050] For such a modified VDSL-TDD transmission with 512 tones, the first stage 34 is bypassed by a multiplexer 42, and the radix of last stage 36 is chosen equal to 2.

[0051] For a modified VDSL-TDD transmission with 256 tones, the two first stages 34 are bypassed by multiplexer 40, and the radix of last stage 36 is chosen equal to 4.

[0052] Finally, for the VDSL transmission of figure 5 with 4096 tones, none of the stages is bypassed, the radix of the last stage 36 is chosen equal to 4, and the frequency of clock CK is chosen equal to 35.328 MHz.

[0053] An FFT circuit with a selectable number of outputs is constructed in the same manner as the IFFT circuit of figure 7. The differences are that the first stage is preceded by a real to complex converter which provides the real and imaginary parts of each complex coefficient in reverse order. The initial order is re-established at the output of the last stage, which is not followed by a complex to real converter.

[0054] Further information on pipeline IFFT and FFT circuits can be found, for example, in "A Fast Single-Chip Implementation of 8192 Points, FFT", IEEE Journal of Solid State Circuits, Vol. 30, N°3, March 1995, Pidet, Castelain, Senn, Blanc.

[0055] It is devised, for VDSL-TDD and VDSL "Zipper" modems, that the tones will be used in an initial phase to transmit modem identification signatures. In other words, a transmitting modem, before establishing a communication, will send a signal conveying specific tones or "bare" carriers, chosen depending on the standard among the possible tones. The receiving modem will detect which tones are present in the signal and identify the standard accordingly. For this purpose, the receiving modem should be "tuned-in" on the transmitting modem from the start, i.e. use at least the tones used by the transmitting modem. Every 8th or every 4th tone of a VDSL Zipper modem is used by a VDSL-TDD modem, whereby such an identification phase is possible in both directions if only the 256 or 512 tones of the VDSL-TDD system are used for the signatures.

[0056] If an ADSL modem should send signatures using consecutive tones, a modem according to the invention should be consistent with figure 5, i.e. use a tone spacing of 4.3125 KHz. However, since the signatures are not yet standardized, it may be devised that an ADSL modem will send signatures using only every p^{th} tone, where p is a power of 2. In this case, a modem having variable size IFFT and FFT circuits according to the invention may initially use a tone spacing of 4.3125p KHz and 2048/p or 4096/p tones and be switched to use 128 or 256 tones with a spacing of 4.3125 KHz upon identifying a remote ADSL modem.

[0057] Figure 8 partially and schematically shows an architecture of a universal DSL modem incorporating IFFT and FFT circuits 12' and 20' as described above. Elements shown in previous figures are designated by same reference characters. The IFFT circuit 12' is preceded by a mapper 50 which associates complex coefficients to outgoing digital words. Circuit 19 which adds cyclic prefixes and cyclic suffixes to the symbols provided by IFFT circuit 12' also achieves pulse shaping. A windowing or frequency weighted averaging is achieved at 52 on the data provided by time domain equalizer 26 to FFT circuit 20'. The output of FFT circuit 20' is successively processed by a frequency domain equalizer 54, a radio frequency interference canceller 56 and a demapper 58 which achieves the inverse function of mapper 50.

[0058] The IFFT and FFT circuits 12' and 20' are controlled by a controller 60 as described above in relation with figure 7. Controller 60 also sets the sampling frequency of analog-to-digital converter 24 at the operating frequency of the IFFT and FFT circuits. Moreover, controller 60 bypasses the time domain equalizer 26 and the radio frequency interference canceller 26, as shown by switches, when the number of tones used by the system is equal to 2048 or 4096.

[0059] Elements of the architecture of figure 8 which are not further described are conventional and can be found in modems for existing standards, such as ADSL and ADSL-Lite (disclosed in Standard T1.413).

Claims

1. A digital subscriber line transmission system using QAM modulation on several equally spaced discrete tones, characterized in that, at a high transmission rate, the system uses N = 2048/p or 4096/p tones spaced by 4.3125p KHz, where p is a power of 2.

2. The system of claim 1, characterized in that, for transmitting at a low transmission rate according to an ADSL standard, only the first n = 128 or 256 tones are used with p = 1.

3. The system of claim 2, characterized in that it comprises, on the transmitter side:

   - an inverse fast Fourier transform (IFFT) circuit (12) having N frequency domain value inputs corresponding to said tones, among which only the first receive values corresponding to the n used tones, the remaining inputs being zeroed,
   - a decimator (30) providing one sample for every r samples output by the IFFT circuit, with r = N/n, and
   - a digital-to-analog converter (14) coupled between the decimator and a subscriber line (10).